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A GRAPHICAL FORM FOR APPLYING THE ROSIN AND RAMMLER EQUATION TO THE SIZE DISTRIBUTION OF BROKEN COAL

BY

W. S. LANDERS AND W. T. REID

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A GRAPHICAL FORM FOR APPLYING THE ROSIN AND RAMMLER EQUATION TO THE SIZE DISTRIBUTION OF BROKEN COAL[1]

By W. S. Landers[2] and W. T. Reid[3]

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INTRODUCTION

Analysis of the size consist of broken coal has been extended in recent years beyond the mere representation of the relative quantities of the various sizes present in a given lot of the material. Fundamental characteristics of the coal related to the process of breakage fix the distribution of sizes, and it has been found by Rosin and Rammler[4] that a relatively simple law governs this property. Bennett[5] has described a graphical method of expressing the relationship, and by its use considerable simplification in the expression of size distribution is possible.

1/ The Bureau of Mines will welcome reprinting of this paper provided the following footnote acknowledgment is used: "Reprinted from Bureau of Mines Information Circular 7346."

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4/ Rosin, P., and Rammler, E., The Laws Governing the Fineness of Powdered Coal: Jour. Inst. Fuel, vol. 7, October 1933, pp. 29-36.

5/ Bennett, J. G., Broken Coal: Jour. Inst. Fuel, vol. 10, October 1936, pp. 22-39.

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Several investigators have described the use of the Rosin and Rammler relationship in evaluating the size consist of coal. Bennett[6] applied it to studies on broken coal and used this method to express degradation occurring in stoker screws. Geer and Yancey[7] investigated the accuracy of the method and showed its applicability to several samples of coal, coke, and other materials. The success of this method applied to broken coal was noted by Austin[8] in his discussion of various methods of plotting size distribution. Vogel and Quass[9] suggested that the parameters of the Rosin and Rammler equation be used to express the friability of coal. Landry[10] showed the application of the method in considering the "inner percentages" resulting from decapitation to produce a resultant coal from run-of-mine, and Scott[11] used this relationship in determining the original size consist of screened coal. Many of these investigators have also tabulated the results of the calculations required for the preparation of the specially ruled paper used in plotting the Bennett diagram.

Considerable time and painstaking labor, however, are required to rule accurately the base form used in the preparation of such diagrams, and consequently this technique has not been generally used. The authors and other workers in this field have felt the need for a standard graphical form that would obviate the necessity of its special preparation by each individual user.

This paper describes such a form now used by the Bureau of Mines, together with a brief description of its use.

ACKNOWLEDGMENTS

This work was done as a part of the Bureau's general study of the utilization of solid fuels, conducted under the direction of A. C. Fieldner, Chief, Fuels and Explosives Branch. C. H. Schwartz, fuel engineer, prepared the master drawing from which the form was reproduced, its accuracy being the result of his careful and precise workmanship. L. D. Schmidt, J. F. Barkley, and H. F. Yancey have offered valuable suggestions and criticisms in the preparation of this form.

6/ Bennett, J. G., work cited in footnote 5.

7/ Geer, M. R., and Yancey, H. F., Expression and Interpretation of the Size Composition of Coal: Trans. Am. Inst. Met. and Min. Eng., vol. 130, 1938, pp. 250-269.

8/ Austin, J. B., Methods of Representing Distribution of Particle Size: Ind. Eng. Chem., Anal. Ed., vol. 11, 1939, pp. 334-339.

9/ Vogel, J. C., and Quass, F. W., The Friability of South African Coals; Jour. Chem. Met. and Min. Soc., South Africa, vol. 37, March 1937, pp. 469-478, 553-556.

10/ Landry, Bertrand A., Fundamentals of Coal Sampling: Bureau of Mines Bulletin 454, 1944, 127 pp.

11/ Scott, G. S., Application of the Rosin-Rammler Law to the "Missing Sizes" in Screened Coal: Bureau of Mines Rept. of Investigations 3732, 1943, 9 pp.

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ROSIN AND RAMMLER EQUATION

In the references previously cited, a complete discussion of the theory and derivation of the Bennett modification of the Rosin and Rammler equation is presented. For the purpose of this paper, it is only necessary to state the equation and define its terms.

The modified equation used in the preparation of the graphical form is

$$R = 100e^{-\left(\frac{x}{\bar{x}}\right)^n},$$

where R is the "oversize" or cumulative percentage by weight of the material retained on a screen having openings of linear dimension x, e is the base of the natural logarithms, and $\bar{x}$ and n are parameters related to the material being studied. This modification, by making the exponent a pure number, gives the law a dimensionless character and simplifies the graphical treatment, since it can be converted into a linear relationship in which the constants are easily determined and utilized. In applying this equation, it is necessary only to plot $\log \log \frac{100}{R}$ against $\log x$, agreement with the law being indicated if the resulting plot is a straight line. If the base form has been prepared by Bennett's[12] method, n is determined by direct measurement of the slope of this line, and $\bar{x}$ is the size corresponding to the value of this line at R equal to 36.79.

PREPARATION OF THE FORM

The values of $\log \log \frac{100}{R}$ from $R = 1$ to $R = 99$ were calculated to determine the relative spacing of the indicated points on the ordinate scale, while the relative spacing of the screen sizes indicated on the lower abscissa scale were calculated from the logarithms of the screen openings. The upper abscissa scale is logarithmic and, when scaled in millimeters, shows the millimeter equivalents of the points on the lower abscissa scale. In order to permit the direct evaluation of n from a plot on this form, Bennett's criterion that the distance from $R=1$ to $R=99$ on the ordinate scale must equal the distance between 0.0436 and 20.00 on the abscissa was followed in establishing the lengths of the scales.

The original of this graphical form was ruled on Bristol board, approximately twice the size of the final printed form. Great care was taken to obtain an exactly rectangular figure, and the ordinate and abscissa lines were drawn in with an error not exceeding 0.2 millimeter. This original figure was then used directly to prepare the printing plate, the size being reduced optically to that required.

Because of the dimensional instability of paper, resulting largely from changes in humidity, the relationship between the lengths of the two scales on each sheet should be determined before use to permit accurate determination of n by direct measurement. On the original drawing for this

12/ Bennett, J. G., work cited in footnote 5.

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form, the distance from 0.03 to 300 on the top scale is 1.503 times the distance from 1 to 99 on the left scale. If on a given printed sheet this relationship does not exist, a correction must be applied in determining n. For example, if the ratio of these two lengths is 1.492, the true value of n is calculated by multiplying the measured slope of a line plotted on the form by 1.492/1.503.

USE OF THE FORM

The use of the form is illustrated in figure 1. In the upper table shown in this figure, the results of a sieve analysis are given. The cumulative percentages retained, or R values, have been calculated and these values plotted against the corresponding sieve sizes shown on the lower scale. The sieves used for points 7, 8, and 9, however, are not listed on the lower scale, and in order to determine their position the equivalents of the sieve openings in millimeters are determined and the points located from the top scale. For example, a sieve having 1/16-inch openings (point 7) is the same as one having 1.59-millimeter openings. Using the interpolation scale shown on the form, 1.59 is located on the top scale, and point 7 lies directly below it at R = 89. The location of most of the sieves commonly used in this country has been furnished, including both the U. S. Standard and Tyler series.

Another use of the top abscissa scale will be found if ranges of sizes are to be studied other than those usually considered. By disregarding the bottom scale and assigning satisfactory units to the top scale, the form may be used to plot the data for any size range, whether expressed in microns, mils, centimeters, inches, or any other units. Thus the top scale has an unlimited range of dimensions and need be confined to millimeters only when used in conjunction with the bottom scale.

If only round-hole sieves are used, the coarse series designations may be employed directly. If, however, both coarse and fine series sieves have been used in a single sieve analysis, the data must be consistent, the simplest correction being to convert the round-hole coarse series sieve sizes to equivalent square-hole sizes.

In determining n from figure 1, two convenient points A and B were chosen arbitrarily. The X and Y distances to these points were measured as shown in the lower table of figure 1, and the slope of the line, n, was calculated from these values. The value of $\bar{x}$ is shown by the intersection of the plotted line and R = 36.79.

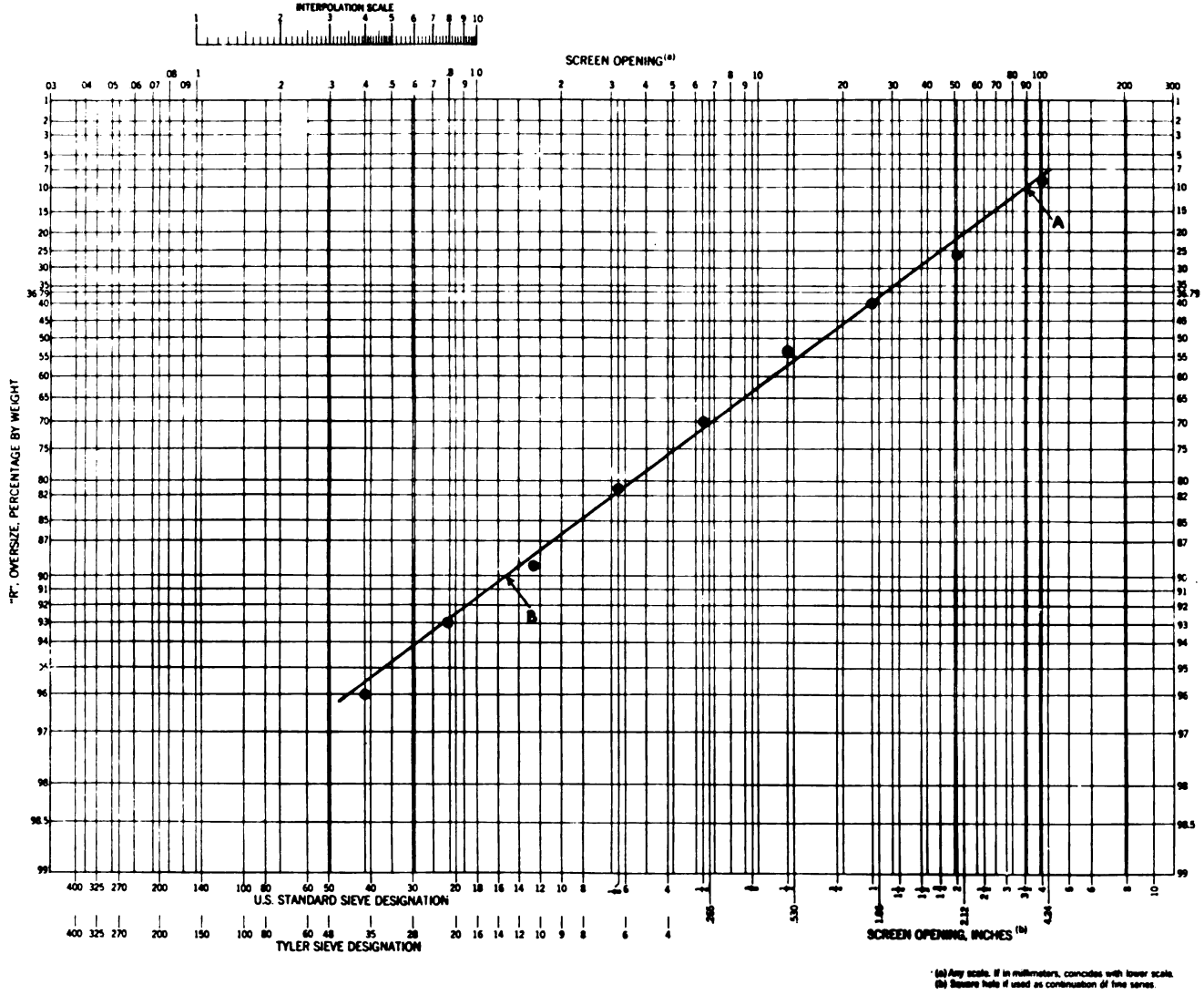
SIGNIFICANCE OF n AND $\bar{x}$

The slope n of the straight-line curve has been termed the "distribution constant" by Bennett[13] and the "distribution factor" by Geer and Yancey.[14] If a sample of coal consisted entirely of particles of exactly

13/ Bennett, J. G., work cited in footnote 5.
14/ Geer, M. R., and Yancey, H. P., work cited in footnote 7.

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INTERPOLATION SCALE
SCREEN OPENING(a)
"R", OVERSIZE, PERCENTAGE BY WEIGHT
A
B
U.S. STANDARD SIEVE DESIGNATION
TYLER SIEVE DESIGNATION
SCREEN OPENING, INCHES (b)
(a) Any scale. If in millimeters, coincides with lower scale.
(b) Square holes if used as continuation of fine series.

Sample No. 2 Test No. —

Material: Run of Mine Coal
Bull. 234, Bur. of Mines, 1925, p. 37

Sieve Analysis by: —
Date —

Plotted by: C.H.S.
Date 7-24-45

Weight of gross sample: —

Weight of test sample: —

Sieve Analysis:

Point No.	Sieve Opening	Percentage Retained	Percentage Cumulative
1	4"	9	9
2	2"	17	26
3	1"	14	40
4	½"	14	54
5	¼"	16	70
6	⅛"	11	81
7	1/16"		
	(1.59 mm)	8	89
8	1/32"		
	(0.79 mm)	4	93
9	1/64"		
	(0.40 mm)	3	96
—	-1/64"	4	100

Characteristics:

Point	Percentage	X, inches	Y, inches
A	10	10.90	7.50
B	90	5.10	3.31
	Difference	5.80	4.19

Distribution coefficient, n: 0.722
Absolute size constant, k: 1.11 inches (28.1 mm)

References.
Rosin, P., and Rammler, E., The Laws Governing the Fineness of Powdered Coal: Jour. Inst. Fuel, vol. 7, October 1933, p. 36.
Bennett, J.G., Broken Coal: Jour. Inst. Fuel, vol. 10, October 1936, pp. 27-39.
Scott, G.S., Application of the Rosin-Rammler Law to the "Mapping Sizes" in Screened Coal: Bureau of Mines Rept. of Investigations 3732, 1943, 9pp.
Landry, Bertrand A., Fundamentals of Coal Sampling: Bureau of Mines Bull. 464, 1944, 127 pp.

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PITTSBURGH, PA.

GRAPHICAL FORM FOR REPRESENTING DISTRIBUTION OF SIZES OF BROKEN COAL.

Figure 1.--A typical application of the graphical form for applying the Rosin and Rammler equation to the size distribution of broken coal.

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the same size, the plot would be vertical, and the slope would be infinite; as the size distribution of the coal in the sample becomes wider, the slope of the line decreases. The relative dustiness of the coal, or the percentage of fines, tends to increase with decreasing values of n. For most broken coals, the value of n determined from the sieve analysis usually lies between 0.7 and 1.3.

The constant $\bar{x}$ is Bennett's "absolute size constant" and corresponds to "k" or the "size factor", used by Geer and Yancey. It is a measure of the size of the material, has the dimensions of length, and is determined by the sieve opening on which 36.79 percent of the sample by weight would be retained.

To illustrate the significance of these constants, assume that the sieve analyses of two coals M and N have been determined over the same set of screens and that these analyses have been plotted on the form discussed in this paper. Assume also that the values of the constants found for coal M are $n = 0.90$ and $\bar{x} = 1.25$ inches; and for coal N, $n = 0.75$ and $\bar{x} = 0.90$ inch. Knowing that these two samples agreed with the Rosin and Rammler law, it would be possible to reconstruct their complete sieve analyses. For example, for coal M, a line drawn through the point $R = 36.79$ and $x = 1.25$ inches and having a slope of 0.90 would synthesize the complete sieve analysis of the material for any set of sieves desired. Also, by use of the constants, coals M and N can be compared. Because of its higher $\bar{x}$ value, coal M is coarser than coal N; and because of its higher n value, coal M is more uniform in size than is coal N. By use of these parameters other useful comparisons can be made between the two materials, helpful in many fields of fuel utilization and preparation.

SUMMARY

A printed form for use in plotting the size consist of samples of broken coal has been described. This form was prepared as a convenience in applying the Bennett modification of the Rosin and Rammler equation to the interpretation of size-consist data. The significance of the constants used in this equation have been briefly described and an example of their application given.

A sample copy of this graphical form, approximately 12 inches by 18 inches, printed on paper suitable for use with ink, may be obtained free upon request of the Bureau of Mines, Washington, 25, D. C.

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